US009107293B2

(12) **United States Patent**
Fitz-Patrick et al.

(10) **Patent No.: US 9,107,293 B2**
(45) **Date of Patent: Aug. 11, 2015**

(54) **ELECTRONICS ENCLOSURES WITH HIGH THERMAL PERFORMANCE AND RELATED SYSTEM**

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(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 175 days.

(21) Appl. No.: **13/469,798**

(22) Filed: **May 11, 2012**

(65) **Prior Publication Data**

US 2013/0299232 A1 Nov. 14, 2013

(51) **Int. Cl.**

H05K 7/20	(2006.01)
H05K 5/02	(2006.01)
B22D 25/02	(2006.01)
B22D 19/00	(2006.01)
B22D 19/04	(2006.01)

(52) **U.S. Cl.**
CPC ***H05K 5/02*** (2013.01); ***B22D 19/0072*** (2013.01); ***B22D 19/04*** (2013.01); ***B22D 25/02*** (2013.01); ***H05K 7/20645*** (2013.01)

(58) **Field of Classification Search**
CPC H05K 7/20645
USPC 361/694, 699, 702, 714
See application file for complete search history.

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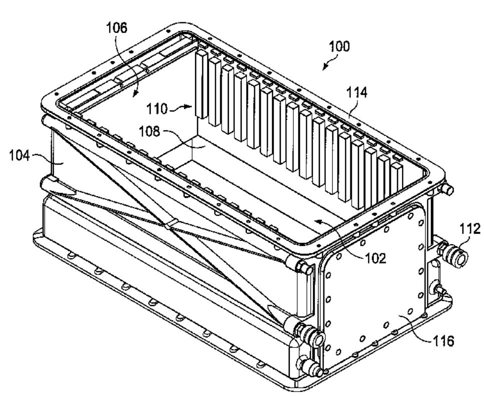
Primary Examiner — Hung V Ngo

(57) **ABSTRACT**

Various apparatuses, methods, and systems are provided for cooling electronic components. For example, an apparatus includes an electronics enclosure having multiple ribs configured to separate electronic components. The apparatus also includes at least one fluid transport structure encased within the electronics enclosure. Each fluid transport structure includes multiple pipes and multiple flow channels. The flow channels are located within the ribs of the electronics enclosure, and the pipes are configured to transport cooling fluid to and from the flow channels. The fluid transport structure(s) and the electronics enclosure are formed from different materials. The at least one fluid transport structure can be resistant to corrosion caused by the cooling fluid, and the electronics enclosure can be susceptible to corrosion caused by the cooling fluid. As an example, the at least one fluid transport structure could consist essentially of nickel, and the electronics enclosure could consist essentially of aluminum.

22 Claims, 13 Drawing Sheets



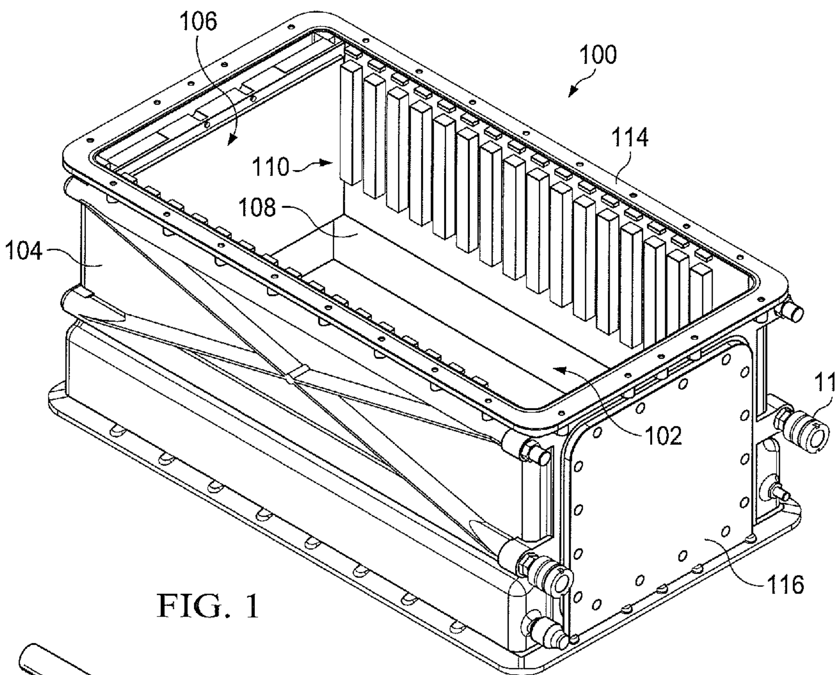


FIG. 1

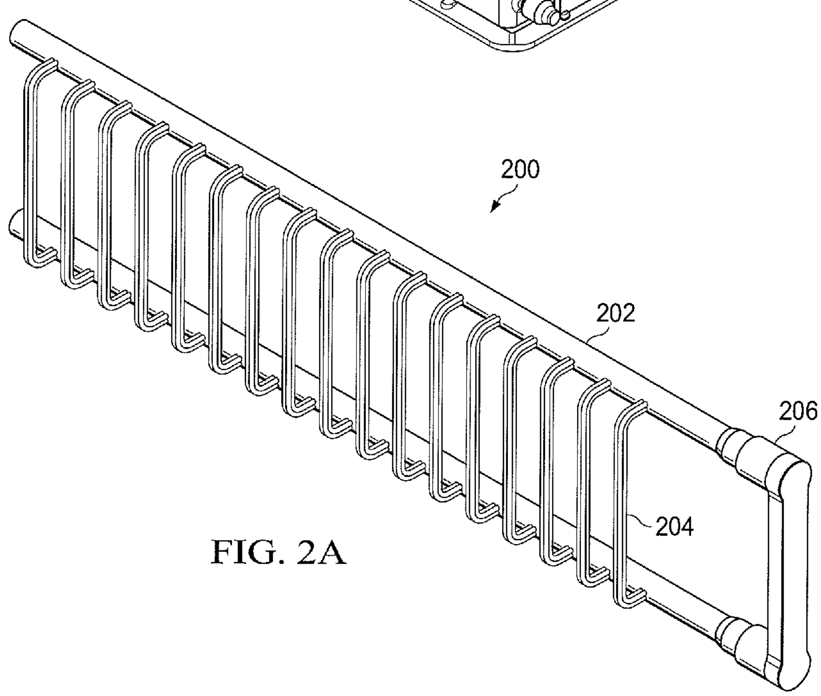


FIG. 2A

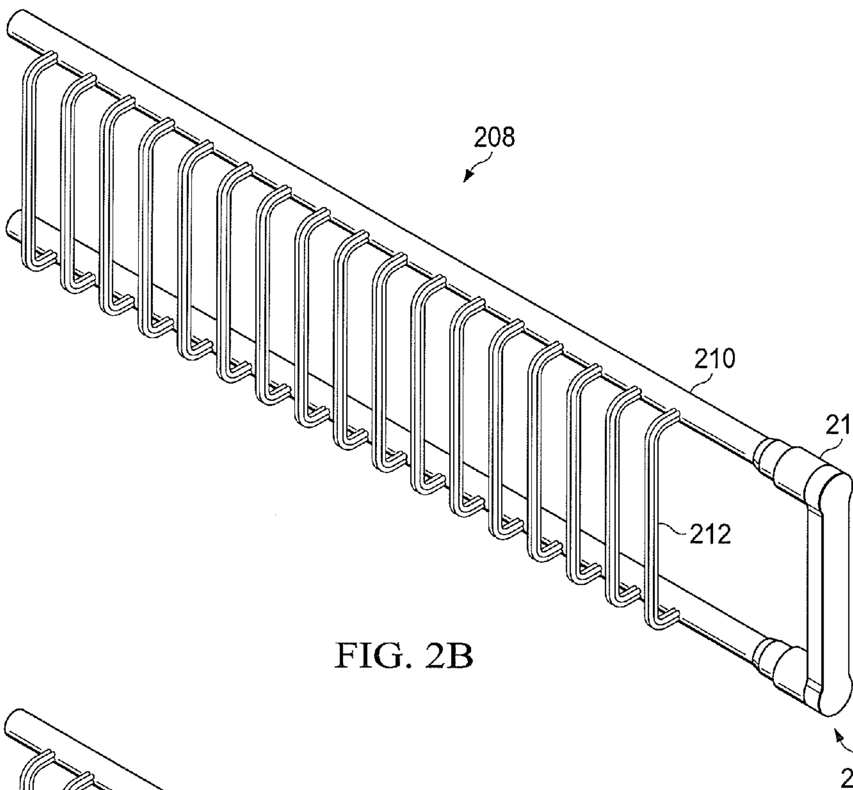


FIG. 2B

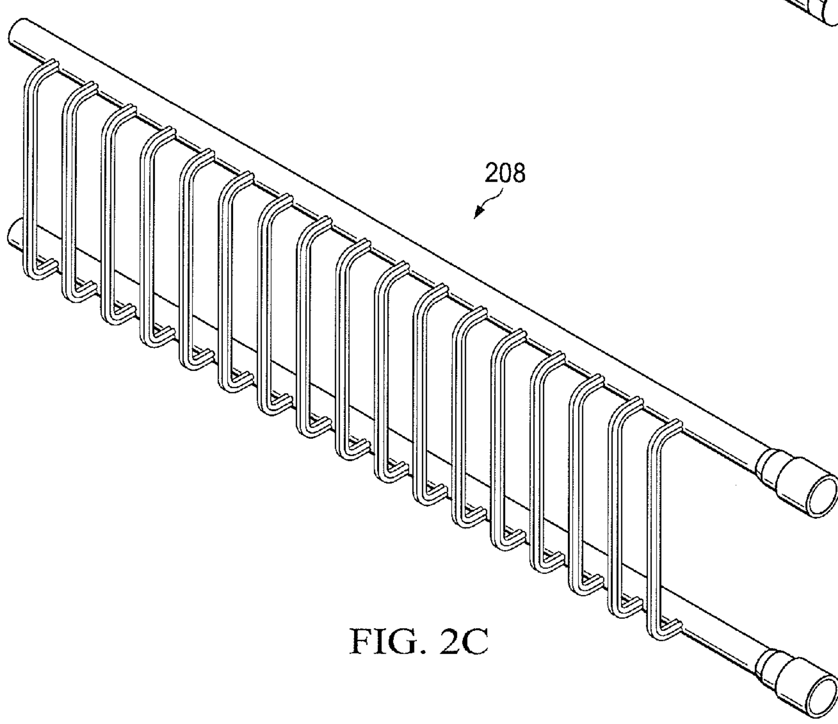


FIG. 2C

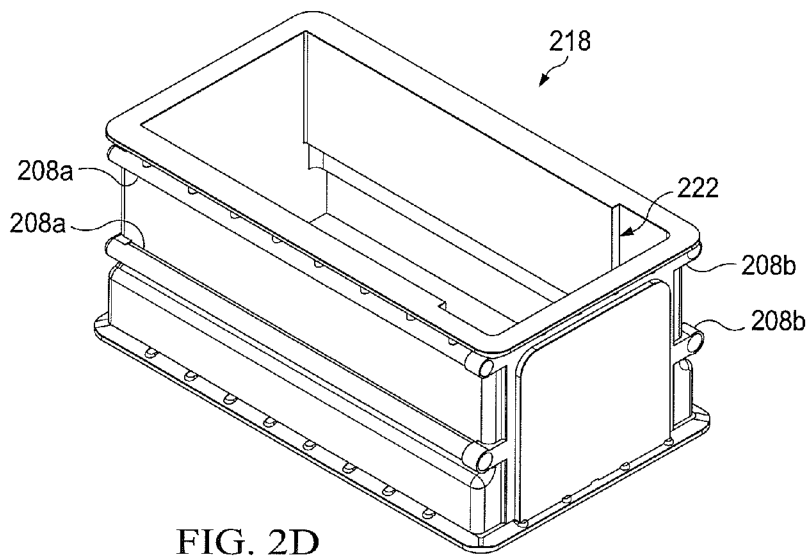


FIG. 2D

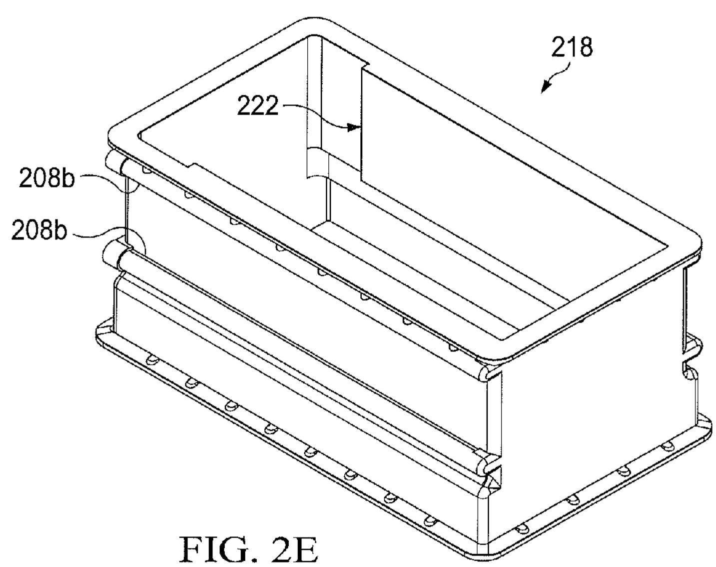


FIG. 2E

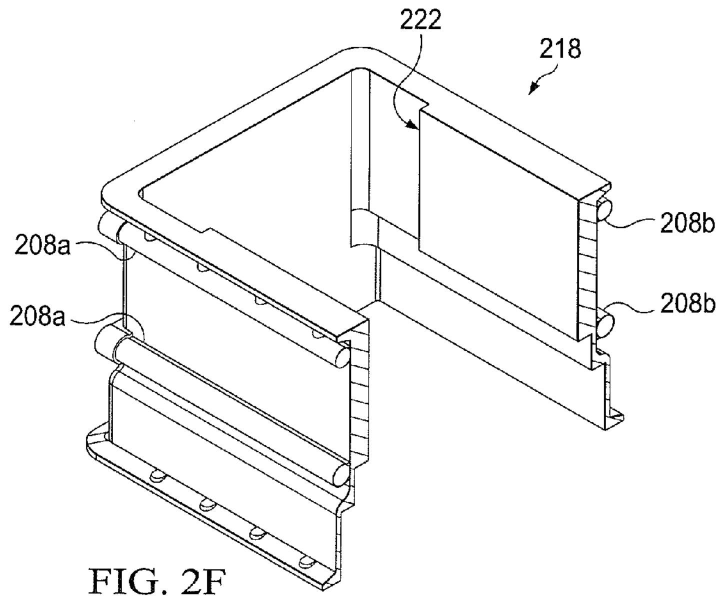


FIG. 2F

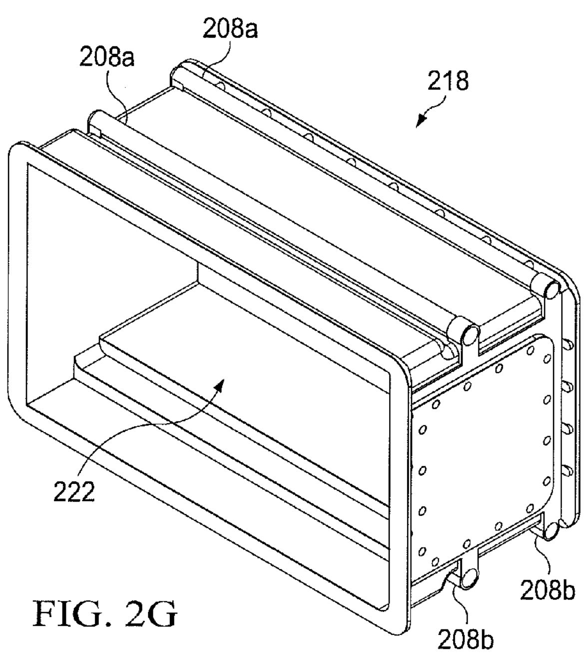


FIG. 2G

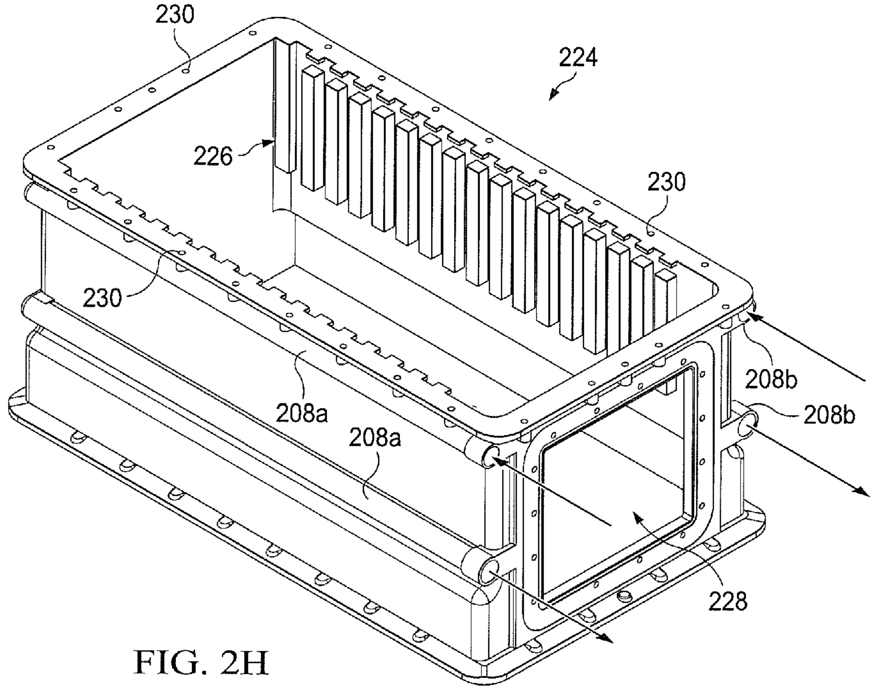


FIG. 2H

FIG. 3A

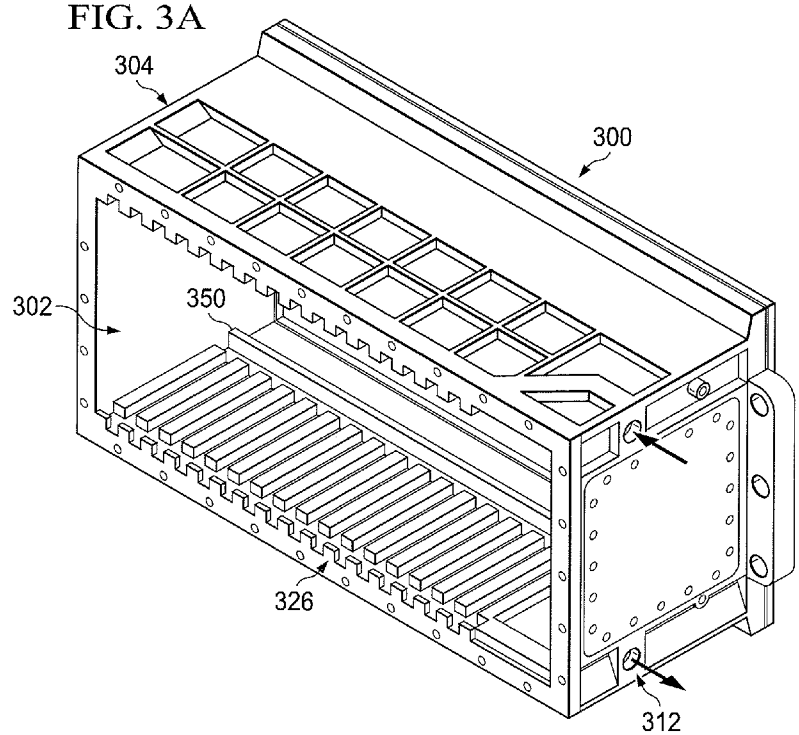


FIG. 3B

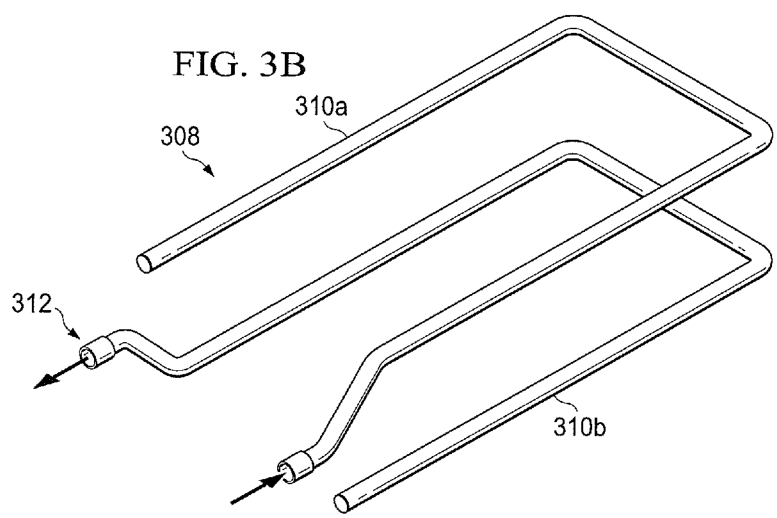


FIG. 4A

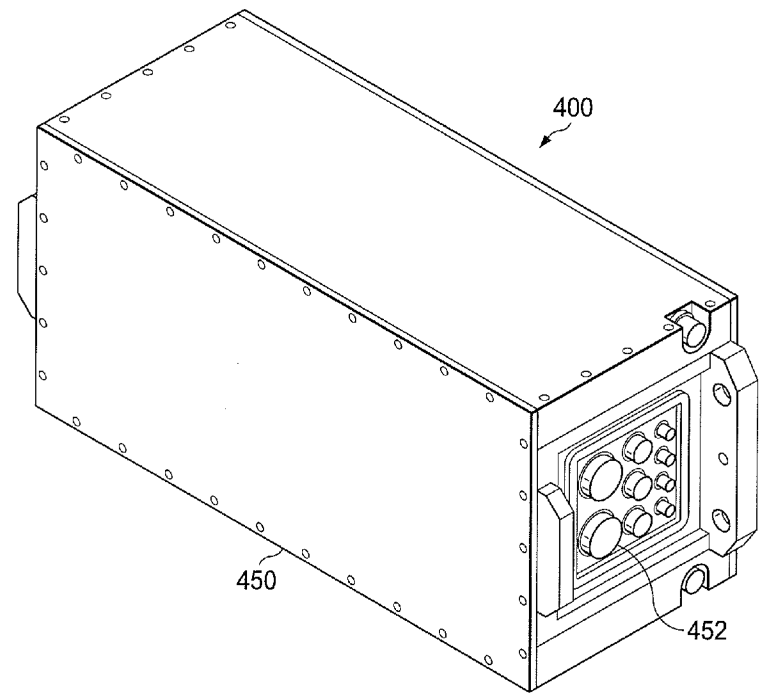
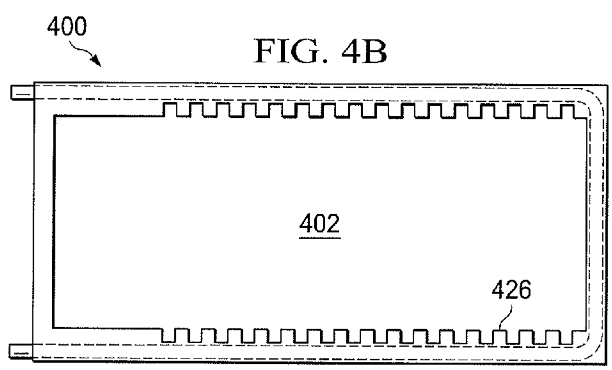


FIG. 4B



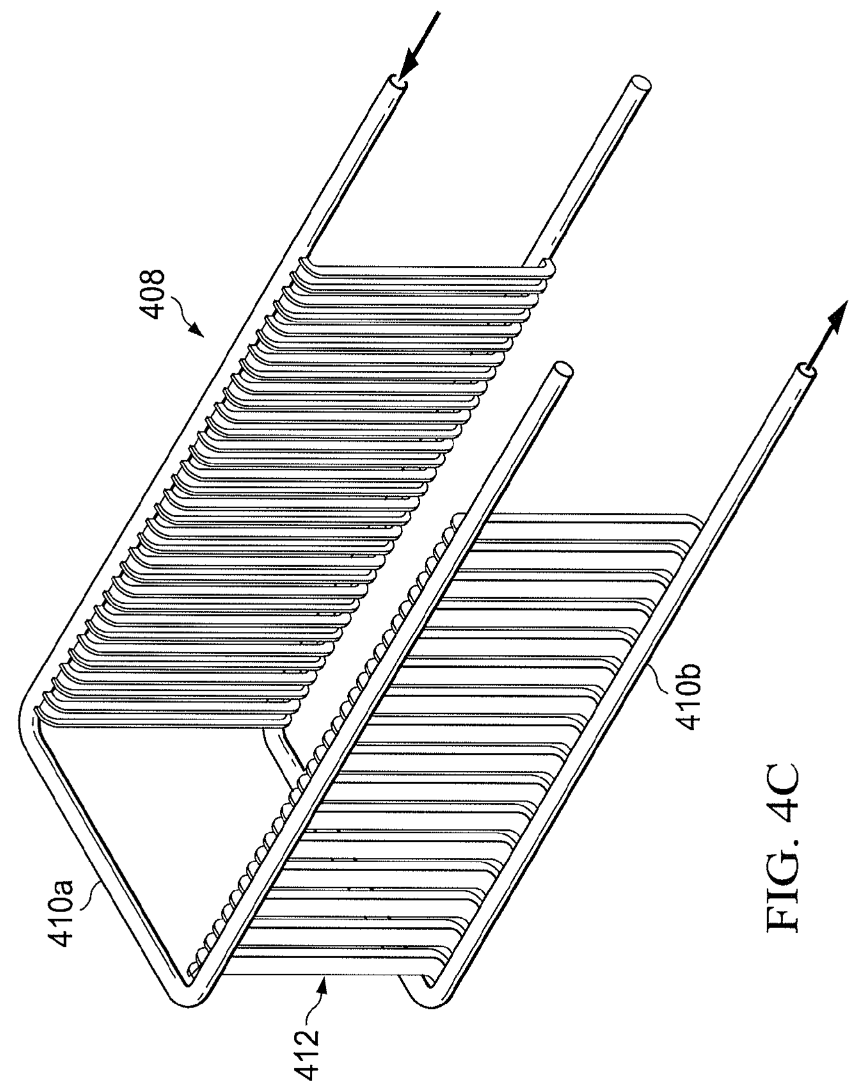


FIG. 4C

FIG. 5A

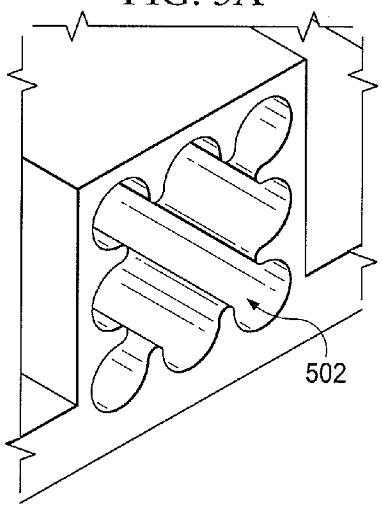


FIG. 5B

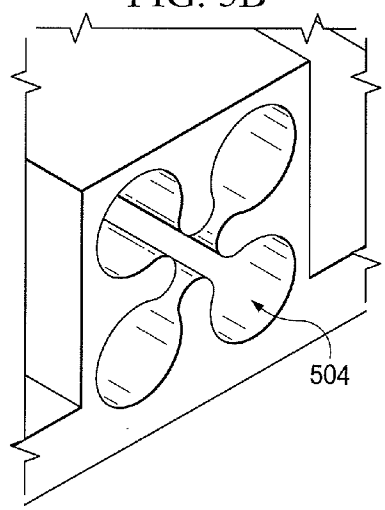


FIG. 5C

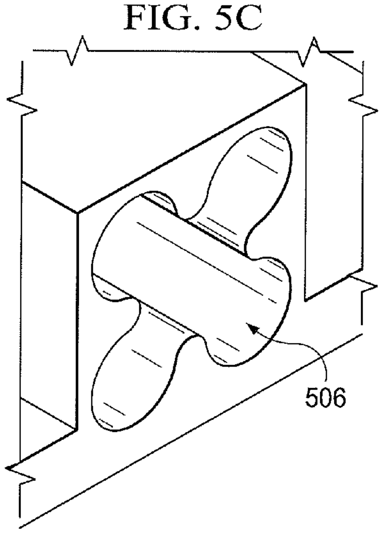
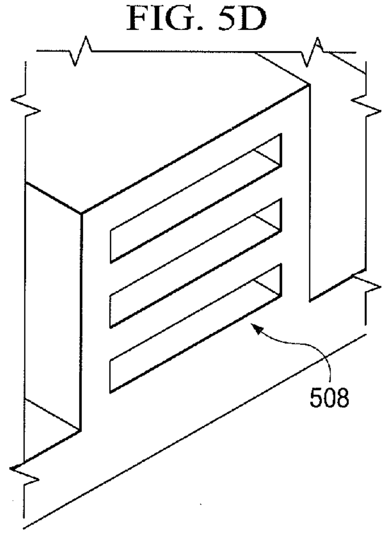


FIG. 5D



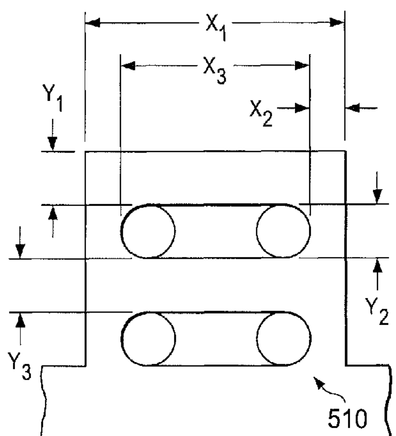


FIG. 5E

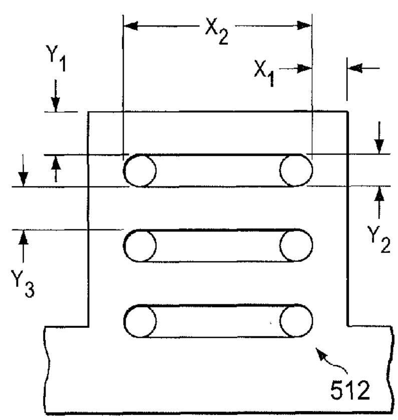


FIG. 5F

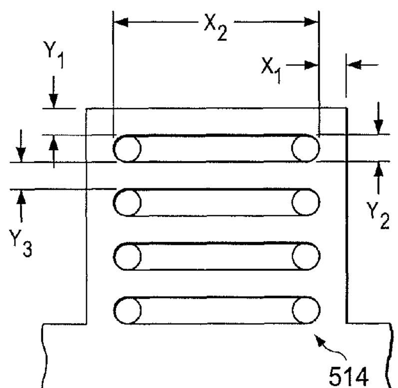


FIG. 5G

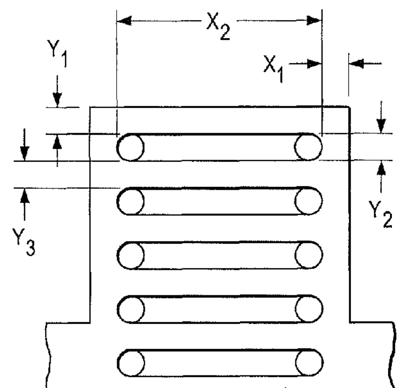


FIG. 5H

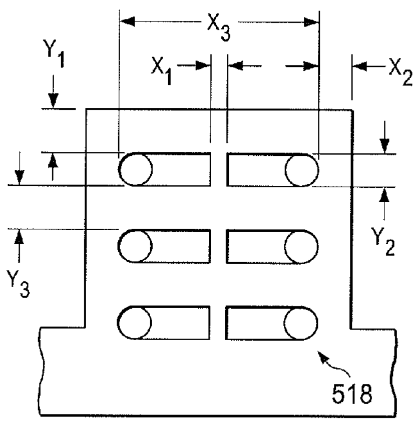


FIG. 5I

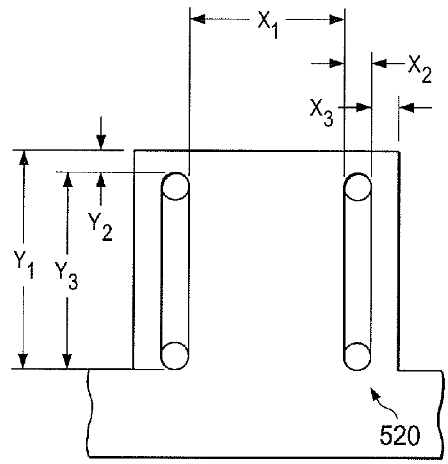


FIG. 5J

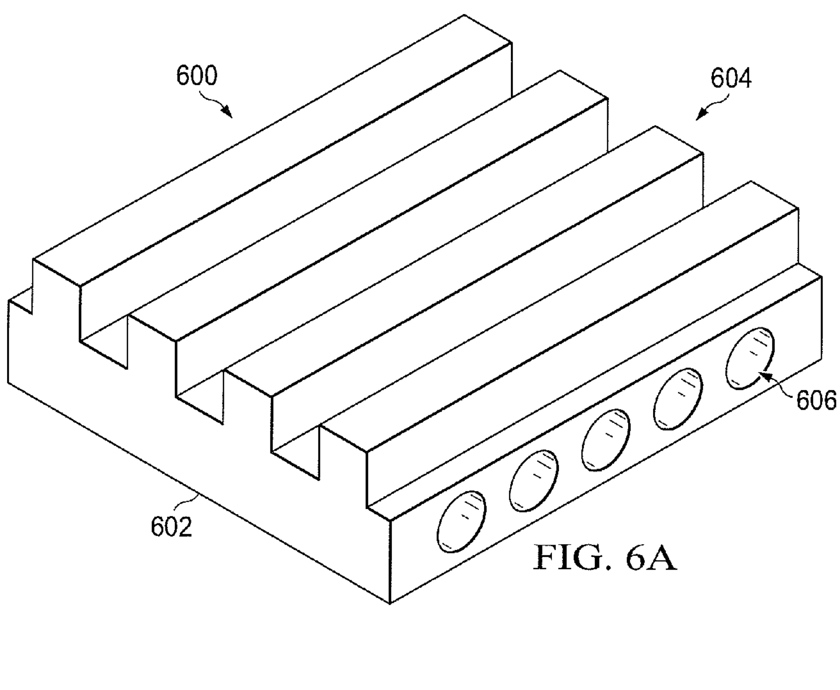


FIG. 6A

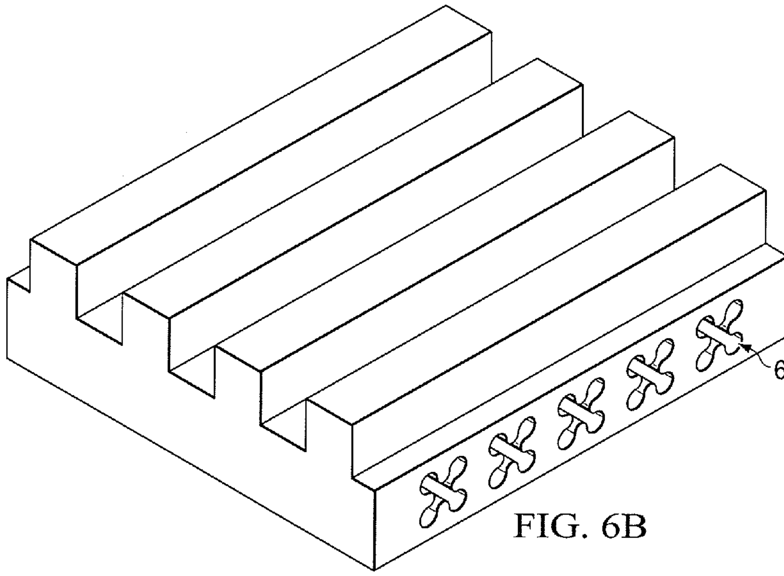


FIG. 6B

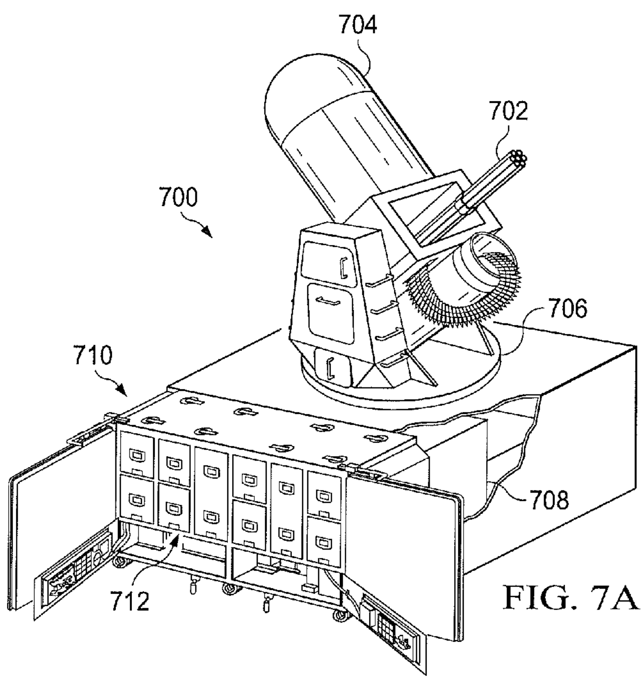
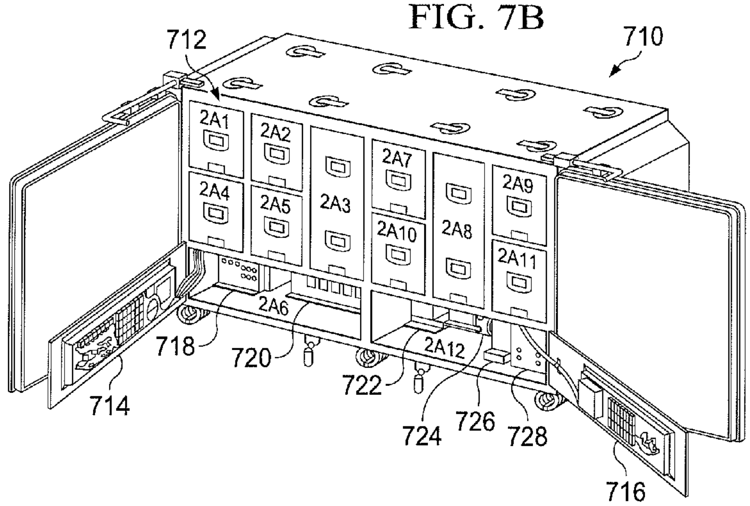


FIG. 7A

FIG. 7B


712
710
2A1
2A2
2A4
2A5
2A3
2A7
2A10
2A8
2A9
2A11
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2A12
714
718
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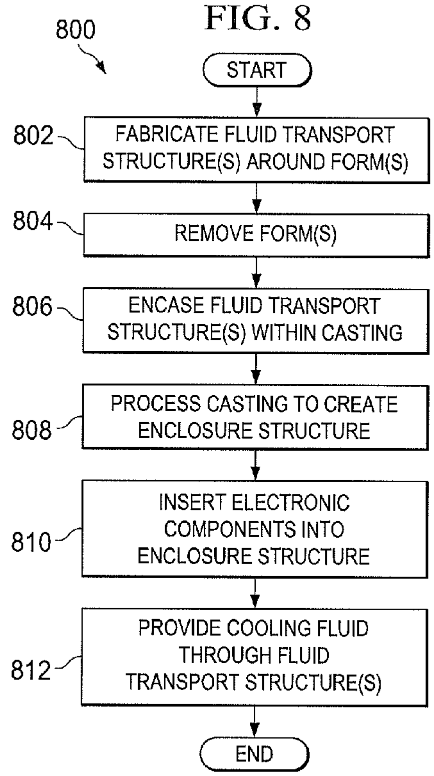
722
724
726
728
716

FIG. 8


800
START
802
FABRICATE FLUID TRANSPORT STRUCTURE(S) AROUND FORM(S)
804
REMOVE FORM(S)
806
ENCASE FLUID TRANSPORT STRUCTURE(S) WITHIN CASTING
808
PROCESS CASTING TO CREATE ENCLOSURE STRUCTURE
810
INSERT ELECTRONIC COMPONENTS INTO ENCLOSURE STRUCTURE
812
PROVIDE COOLING FLUID THROUGH FLUID TRANSPORT STRUCTURE(S)
END

ELECTRONICS ENCLOSURES WITH HIGH THERMAL PERFORMANCE AND RELATED SYSTEM

GOVERNMENT LICENSE RIGHTS

This invention was made with government support under Contract No. N00014-07D-0578 awarded by the U.S. Department of Defense. The government may have certain rights in the invention.

TECHNICAL FIELD

This disclosure is generally directed to cooling systems for electronics. More specifically, this disclosure is directed to electronics enclosures with high thermal performance and related system and method.

BACKGROUND

Various types of cooling systems have been developed for cooling electronic components. Simple cooling systems often involve the use of one or more fans for blowing cooler air over electronic components or pulling hotter air away from electronic components. High-power and densely-packaged electronics often require the use of liquid-based cooling systems, which deliver a cooling fluid to areas around electronic components. Typical cooling fluids include oil and corrosion-inhibited ethylene glycol and water. Many liquid-based cooling systems involve the use of stainless steel or aluminum structures.

SUMMARY

This disclosure provides electronics enclosures with high thermal performance and related system and method.

In a first embodiment, a method includes forming at least one fluid transport structure. Each fluid transport structure is fabricated by depositing one or more materials onto a form, and each fluid transport structure includes multiple pipes and multiple flow channels. The method also includes encasing the at least one fluid transport structure in an enclosure casting and processing the enclosure casting to form an electronics enclosure having multiple ribs configured to separate electronic components. The flow channels are located within the ribs of the electronics enclosure and the pipes are configured to transport cooling fluid to and from the flow channels.

In a second embodiment, an apparatus includes an electronics enclosure having multiple ribs configured to separate electronic components. The apparatus also includes at least one fluid transport structure encased within the electronics enclosure. Each fluid transport structure includes multiple pipes and multiple flow channels. The flow channels are located within the ribs of the electronics enclosure and the pipes are configured to transport cooling fluid to and from the flow channels. The at least one fluid transport structure and the electronics enclosure are formed from different materials.

In a third embodiment, a method includes forming at least one fluid transport structure. Each fluid transport structure is fabricated by depositing one or more materials onto a form, and each fluid transport structure includes multiple channels. The method also includes encasing the at least one fluid transport structure in an enclosure casting and processing the enclosure casting to form an electronics enclosure having multiple ribs configured to separate electronic components. The channels are located within multiple walls of the electronics enclosure and are configured to receive a cooling fluid for transporting heat away from the ribs.

Other technical features may be readily apparent to one skilled in the art from the following figures, descriptions, and claims.

BRIEF DESCRIPTION OF THE DRAWINGS

For a more complete understanding of this disclosure and its features, reference is now made to the following description, taken in conjunction with the accompanying drawings, in which:

FIG. **1** illustrates a first example electronics enclosure in accordance with this disclosure;

FIGS. **2**A through **2**H illustrate an example technique for forming the electronics enclosure of FIG. **1** in accordance with this disclosure;

FIGS. **3**A and **3**B illustrate a second example electronics enclosure in accordance with this disclosure;

FIGS. **4**A through **4**C illustrate a third example electronics enclosure in accordance with this disclosure;

FIGS. **5**A through **5**J illustrate example flow channels inside ribs that separate electronic components within an electronics enclosure in accordance with this disclosure;

FIGS. **6**A and **6**B illustrate example channels inside walls of an electronics enclosure in accordance with this disclosure;

FIGS. **7**A and **7**B illustrate an example system using electronics enclosures with high thermal performance in accordance with this disclosure; and

FIG. **8** illustrates an example method for forming an electronics enclosure with high thermal performance in accordance with this disclosure.

DETAILED DESCRIPTION

FIGS. **1** through **8**, described below, and the various embodiments used to describe the principles of the present invention in this patent document are by way of illustration only and should not be construed in any way to limit the scope of the invention. Those skilled in the art will understand that the principles of the present invention may be implemented in any type of suitably arranged device or system.

As noted above, many conventional liquid-based cooling systems involve the use of stainless steel or aluminum structures. Unfortunately, stainless steel often cannot provide adequate thermal performance for densely-packed electronic components. Aluminum is highly conductive and is able to efficiently transfer heat away from electronic components. However, aluminum is also easily corroded by even mildly corrosive materials such as tap water. As a result, these types of conventional liquid-based cooling systems cannot be used in systems where high thermal performance is needed and the cooling fluid is corrosive, such as in systems that use deionized water and ethylene glycol without corrosion inhibitors. Also, some conventional liquid-based cooling systems require the use of multiple cooling fluids with separate fluid loops and heat exchangers, which increase the size, complexity, maintenance, performance monitoring, and cost of those cooling systems.

FIG. **1** illustrates a first example electronics enclosure **100** in accordance with this disclosure. As shown in FIG. **1**, the electronics enclosure **100** defines an enclosed space **102** between its walls **104**. Multiple circuit boards **106** or other electronic components are placed within this enclosed space **102**. The circuit boards **106** are electrically coupled to a backplane **108** or other structure within the electronics enclosure **100**. The circuit boards **106** are inserted between ribs **110** formed along two inner surfaces of the walls **104**. The circuit boards **106** can be secured within the electronics enclosure **100** using any suitable technique, such as with wedge locks.

In this example, the electronics enclosure **100** supports liquid-based cooling of the circuit boards **106** or other electronic components placed within the enclosed space **102** using heat conduction through the ribs **110**. As a result, conduction cooled-type cards or other circuit boards **106** can be used in the electronics enclosure **100**. In FIG. **1**, cooling fluid is delivered and recovered through various ports **112** in the electronics enclosure **100**. The cooling fluid flows through pipes within the walls **104** and through flow channels within the ribs **110**, which helps to remove heat away from the circuit boards **106**. As described below, the pipes and flow channels in the electronics enclosure **100** are fabricated from one or more materials resistant to corrosion. Other portions of the electronics enclosure **100** can be fabricated from one or more other materials that are vulnerable to corrosion from the cooling fluid. However, because the cooling fluid flows through pipes and flow channels that are resistant to corrosion, the electronics enclosure **100** as a whole can be used in applications where corrosive cooling fluids are used. Note that platings or coatings can be applied to the outer surface of the enclosure **100** to provide corrosion resistance to the enclosure **100**.

In this document, the phrase "flow channel" refers to any path within a rib of an enclosure through which a fluid can flow. A flow channel can have any suitable length, cross-sectional shape, or other characteristics. Also, in this document, the term "pipe" refers to any path through which a fluid can flow for delivery to one or more flow channels. Again, a pipe can have any suitable length, cross-sectional shape, or other characteristics.

Note that the size, shape, and dimensions of the electronics enclosure **100** and its component parts are for illustration only, and various changes to these characteristics are within the ordinary skill in the art. For example, the electronics enclosure **100** need not have a generally rectangular cross-section, and it could include any number of ribs **110** and receive any number of circuit boards **106**. Also, the electronics enclosure **100** includes a bottom plate (not shown here) under the backplane **108** or other structure. This bottom plate further defines the enclosed space **102** and can help provide protection against moisture or other external elements. Further, while not shown, the electronics enclosure **100** could include a protective cover that is attached to a surface **114** located at the top of the walls **104**. In addition, a hatch or plate **116** can cover an access passage into the enclosed space **102**. The hatch or plate **116** can have any suitable size, shape, and dimensions and can be secured to a wall **104** of the electronics enclosure **100** in any suitable manner. The hatch or plate **116** can include connectors for coupling to external power, radio frequency, fiber optic, or other cables.

FIGS. **2**A through **2**H illustrate an example technique for forming the electronics enclosure **100** of FIG. **1** in accordance with this disclosure. As shown in FIG. **2**A, the technique begins with a form **200**. The form **200** represents a structure around which another structure is to be formed. In this example, the form **200** includes two cylindrical regions **202** physically attached to rib regions **204**. The cylindrical regions **202** represent areas where pipes for transporting cooling fluid are being formed, and the rib regions **204** represent areas where flow channels for transporting cooling fluid through the ribs **110** are being formed. The form **200** also includes end regions **206**, which include areas where the various ports **112** of the electronics enclosure **100** are being formed. Note that end regions **206** are joined here, which is merely done as a process aid. The form **200** can be fabricated from any suitable material(s) and in any suitable manner. In some embodiments, the form **200** is fabricated by machining an aluminum structure into the appropriate form. In other embodiments, a stereo lithography (SLA) plastic part can be fabricated, such as by using an investment casting of an alloy.

As shown in FIG. **2**B, a fluid transport structure **208** is formed over the form **200**. The form **200** therefore functions as a mandrel for forming the fluid transport structure **208**. The fluid transport structure **208** includes pipes **210**, flow channels **212**, and ports **214**. When used within the electronics enclosure **100**, one pipe **210** transports cooling fluid from one port **214** to the flow channels **212**. The cooling fluid then passes through the flow channels **212**, which provides cooling within the ribs **110** of the electronics enclosure **100**. The cooling fluid then passes through another pipe **210** to another port **214** and exits the electronics enclosure **100**.

The fluid transport structure **208** can be formed from any suitable material(s) resistant to corrosion caused by the cooling fluid to be used. For example, the fluid transport structure **208** can be formed from pure or substantially pure nickel. The fluid transport structure **208** can also be formed in any suitable manner. In some embodiments (such as where the form **200** is fabricated from aluminum), nickel can be electroformed on the form **200**. In other embodiments (such as where the form **200** is fabricated from an SLA plastic part), the plastic part can be sprayed with a conductive paint or other material(s) (such as a copper-based lacquer), and nickel can then be electroformed on the form **200**. The nickel in the fluid transport structure **208** could have any suitable thickness, such as a minimum thickness of about 5 mil (0.005") to about 20 mil (0.02"). Certain portions of the fluid transport structure **208** could also be thicker than other portions, such as when the ports **214** have a thickness that is about 5 mil (0.005") to about 10 mil (0.01") thicker than the pipes **210**.

As shown in FIG. **2**C, all or substantially all of the form **200** is physically removed, leaving the fluid transport structure **208**. The form **200** can be removed in any suitable manner. For example, various portions of the form **200** could be removed using caustic or other chemical etchants, drilling, burning, or any other suitable processing operations. The specific removal technique(s) used can depend at least partially on the material(s) forming the form **200**. The resulting structure can be further processed in any suitable manner to form a finalized fluid transport structure **208**.

Multiple fluid transport structures **208*a*-208*b*** can be fabricated in the manner shown in FIGS. **2**A through **2**C, and an enclosure casting **218** can then be formed as shown in FIGS. **2**D through **2**G. FIG. **2**D illustrates a top and front isometric view of the enclosure casting **218**, and FIG. **2**E illustrates a top and back isometric view of the enclosure casting **218**. Also, FIG. **2**F illustrates a cut away section isometric view of the enclosure casting **218**, and FIG. **2**G illustrates a bottom isometric view of the enclosure casting **218**.

The enclosure casting **218** represents a structure that is formed around the fluid transport structures **208*a*-208*b***. In other words, the fluid transport structures **208*a*-208*b*** are embedded or encased within the enclosure casting **218**. In this example, the fluid transport structures **208*a*-208*b*** are encased in opposite sides of the enclosure casting **218**. The enclosure casting **218** has a form that is similar to the final shape of the electronics enclosure **100**. However, among other things, the enclosure casting **218** includes raised plateaus **222** along two of its inner walls. The raised plateaus **222** represent areas where the flow channels **212** of the fluid transport structures **208** are encased and the ribs **110** are to be formed. The enclosure casting **218** can be formed from any suitable material(s), such as aluminum. The enclosure casting **218** can also be formed in any suitable manner, such as by using the fluid transport structures **208***a*-**208***b* as a mold core and casting aluminum around the fluid transport structures **208***a*-**208***b*. As a particular example, the fluid transport structures **208***a*-**208***b* can be overcast in SLA to create a form and aluminum can be embedded in the SLA form to create the casting.

The enclosure casting **218** is then processed to create a final enclosure structure **224** as shown in FIG. **2**H. The processing includes forming ribs **226** in the raised plateaus **222**. The processing also includes forming an opening **228** in the front wall of the enclosure structure **224**. The processing further includes forming various threaded holes **230** or other structures used to secure a protective cover or plate/hatch to the enclosure structure **224**. Any suitable processing technique could be used to form the ribs, holes, or other structures of the enclosure structure **224** from the enclosure casting **218**, such as by machining an aluminum enclosure casting **218**.

In one aspect of operation, cooling fluid can be pumped, injected, or otherwise provided into one port **214** of each fluid transport structure **208***a*-**208***b*. The fluid flows through one pipe **210** of each fluid transport structure **208***a*-**208***b* to the encased flow channels **212** of that fluid transport structure **208***a*-**208***b*. The fluid flows through the flow channels **212** within the ribs **226**, transporting heat away from the ribs **226** and any electronic components in thermal contact with those ribs **226**. The fluid flows through another pipe **210** of each fluid transport structure **208***a*-**208***b* and exits the enclosure structure **224** through another port **214** of each fluid transport structure **208***a*-**208***b*.

In this way, cooling fluid is delivered to the ribs **226** to help pull heat away from circuit boards or other electronic components within the enclosure structure **224**. Moreover, the fluid transport structures **208***a*-**208***b* can be formed from at least one material that resists corrosion from the cooling fluid (such as nickel). Other portions of the enclosure structure **224** can be formed from at least one other material such as aluminum that is susceptible to corrosion from the cooling fluid (although protective platings or coatings could be used), and the fluid transport structures **208***a*-**208***b* help to prevent most or all of the remainder of the enclosure structure **224** from contacting the cooling fluid. As a result, cooling fluids that might otherwise be unsuitable for use in certain applications due to their corrosive effects (such as tap water or de-ionized water and ethylene glycol without corrosion inhibitors) may be used in the electronics enclosure **100**. Moreover, because the enclosure **100** is fabricated in this manner, the walls **104** are contiguous and do not require the use of bolted joints or other connections that could leak. In addition,

Although FIG. **1** illustrates one example of an electronics enclosure **100** and FIGS. **2**A through **2**H illustrate one example of a technique for forming the electronics enclosure **100**, various changes may be made to FIG. **1** and FIGS. **2**A through **2**H. For example, various features of the electronics enclosure **100** (such as the number of ribs or external surface features) are for illustration only. Also, any other suitable technique could be used to form each fluid transport structure **208** or other structures of the electronics enclosure **100**.

FIGS. **3**A and **3**B illustrate a second example electronics enclosure in accordance with this disclosure. In particular, FIG. **3**A illustrates a top isometric view of an electronics enclosure **300**, and FIG. **3**B illustrates portions of a fluid transport structure within the electronics enclosure **300**.

As shown in FIG. **3**A, the electronics enclosure **300** is similar in structure to the electronics enclosure **100**. The electronics enclosure **300** defines an enclosed space **302** between its walls **304**. Multiple circuit boards or other electronic components can be placed within the enclosed space **302** and electrically coupled to a backplane or other structure. The circuit boards are inserted between ribs **326** formed along two inner walls of the electronics enclosure **300**. A rib **350** is used to hold a backplane or other structure into which circuit boards can be inserted (a similar structure could be used in FIG. **1**).

In this example, the electronics enclosure **300** supports liquid-based cooling of the circuit boards or other electronic components using two ports **312**. As shown in FIG. **3**B, a fluid transport structure **308** is used within the electronics enclosure **300**. Here, two U-shaped pipes **310***a*-**310***b* are included in the fluid transport structure **308**. One pipe **310***a* of the fluid transport structure **308** delivers fluid to flow channels located in the ribs **326** on both sides of the electronics enclosure **300**. Another pipe **310***b* of the fluid transport structure **308** receives fluid that has traveled through the flow channels in the ribs **326** on both sides of the electronics enclosure **300**. One end of each pipe **310***a*-**310***b* is terminated or blocked to prevent the flow of cooling liquid out of that end of the pipe. In this way, one port **312** can be used to deliver cooling fluid to both sides of the electronics enclosure **300**, and one port **312** can be used to recover cooling fluid from both sides of the electronics enclosure **300**.

A process similar to that shown in FIGS. **2**A through **2**H could be used to fabricate the electronics enclosure **300** of FIG. **3**. For example, the fluid transport structure **308** could be formed by depositing nickel or other material(s) on an aluminum or other form and then removing the form. An aluminum or other enclosure casting can then be formed around the fluid transport structure **308**, and the enclosure casting can be machined or otherwise processed to form the ribs **326** and other structures of the electronics enclosure **300**.

FIGS. **4**A through **4**C illustrate a third example electronics enclosure **400** in accordance with this disclosure. The electronics enclosure **400** is similar in structure to the electronics enclosure **300** of FIGS. **3**A and **3**B. For example, the electronics enclosure **400** defines an enclosed space **402** in which multiple circuit boards or other electronic components can be placed and electrically coupled to a backplane or other structure. The circuit boards are inserted between ribs **426** formed along two inner walls of the electronics enclosure **400**. The electronics enclosure **400** also includes a fluid transport structure **408** having U-shaped pipes **410***a*-**410***b* that transport fluid to and from flow channels **412** located within the ribs **426**. In this example, each pipe **410***a*-**410***b* is open at one end and terminated at the other end so that fluid entering one pipe is forced through the flow channels **412** before exiting through the other pipe.

The electronics enclosure **400** also includes a protective cover **450** attached to the top of the electronics enclosure **400**. Note that the various walls and covers of the electronics enclosure **400** could form water-tight seals with adjacent walls or structures to prevent leakage of fluid into the electronics enclosure **400**. The same can be true for the other enclosures described here. The electronics enclosure **400** further includes various connectors **452**, which can be coupled to power, radio frequency, fiber optic, or other cables.

Again, a process similar to that shown in FIGS. **2**A through **2**H could be used to fabricate the electronics enclosure **400** of FIGS. **4**A through **4**C. For example, the fluid transport structure **408** could be formed by depositing nickel or other material(s) on an aluminum or other form, and the form can be removed. An aluminum or other enclosure casting can then be formed around the fluid transport structure **408**, and the enclosure casting can be machined or otherwise processed to form the ribs **426** and other structures of the electronics enclosure **400**.

In all of the embodiments described above, cooling fluid flows through channels formed from nickel or other material(s) resistant to corrosion caused by the cooling fluid. The other portions of the electronics enclosures could be formed from aluminum or other material(s). The use of aluminum is beneficial since it is inexpensive, relatively lightweight, thermally conductive, and easily machined, and various techniques are known for fabricating aluminum structures. The use of nickel is beneficial since it is easily produced using standard techniques and provides high thermal performance. Nickel is also resistant to corrosion caused by de-ionized water-based cooling fluids or other mildly corrosive liquids.

In these embodiments of the electronics enclosures, the conduction path of heat away from electronic components travels directly into the walls of the electronics enclosures, which form card guides for the circuit boards. The cooling fluid flowing through the walls and ribs of the electronics enclosures has high heat transfer capabilities, thus allowing the removal of large amounts of heat away from the electronic components. The exact paths of the pipes through an electronics enclosure can be designed to provide optimized heat transfer performance, and the design can vary depending on various factors (such as the outer shape of the enclosure and the types of circuit boards being cooled). For example, the pipes could be modeled using three-dimensional computer-aided drafting (CAD) software, and simulations could be performed to identify the expected performance of the enclosure's cooling system.

As noted above, in the embodiments described above, the electronics enclosures can be fabricated by creating one or more fluid transport structures and then encasing the structure(s) in aluminum or other material(s). After fabrication of the fluid transport structures, the structures can be tested for leaks in any suitable manner (such as using helium testing) prior to encasement. The fluid transport structures can be fabricated to have all necessary fittings and threaded regions prior to incorporation into an enclosure casting.

Although FIGS. **3**A and **3**B and FIGS. **4**A through **4**C illustrate other examples of electronics enclosures, various changes may be made to FIGS. **3**A and **3**B and FIGS. **4**A through **4**C. For example, various features of each electronics enclosure (such as the number of ribs or external surface features) are for illustration only. Also, any suitable technique could be used to form the electronics enclosures.

FIGS. **5**A through **5**J illustrate example flow channels inside ribs that separate electronic components within an electronics enclosure in accordance with this disclosure. More specifically, FIGS. **5**A through **5**J illustrate possible cross-sectional shapes of the flow channels inside the ribs of an electronics enclosure. These different cross-sectional flow channel shapes could be used in any of the electronics enclosures described above.

As shown in FIG. **5**A, a flow channel **502** has a cross-sectional shape that can be generally described as having a central area surrounded by eight interconnected partial and near-complete circular areas. As shown in FIG. **5**B, a flow channel **504** has a cross-sectional shape that can be generally described as having four circular areas interconnected via thinner paths to a smaller central circular area. As shown in FIG. **5**C, a flow channel **506** has a cross-sectional shape that can be generally described as having four circular areas interconnected via thicker paths to a larger central circular area.

As shown in FIG. **5**D, a collection of flow channels **508** includes three rectangular channels. FIGS. **5**E through **5**H illustrate collections of horizontal flow channels **510-516** that are rectangular with rounded ends. The following example dimensions could be used in particular implementations of these flow channels. Note that these values are approximate values only. In FIG. **5**E, dimension X_1 could be 0.475 inches, dimension X_2 could be 0.0625 inches, and dimension X_3 could be 0.350 inches. Also, dimensions Y_1, Y_2, and Y_3 could each be 0.100 inches. In FIG. **5**F, dimension X_1 could be 0.0625 inches, and dimension X_2 could be 0.350 inches. Also, dimensions Y_1 and Y_3 could each be 0.075 inches, and dimension Y_2 could be 0.060 inches. In FIG. **5**G, dimensions X_1, Y_1, Y_2, and Y_3 could each be 0.050 inches, and dimension X_2 could be 0.375 inches. In FIG. **5**H, dimensions X_1, Y_1, Y_2, and Y_3 could each be 0.050 inches, and dimension X_2 could be 0.375 inches. FIG. **5**I illustrates a three-by-two collection of horizontal flow channels **518** that are rectangular, each with one rounded end. In FIG. **5**I, dimension X_1 could be 0.030 inches, dimension X_2 could be 0.0625 inches, and dimension X_3 could be 0.350 inches. Also, dimensions Y_1 and Y_3 could each be 0.075 inches, and dimension Y_2 could be 0.060 inches.

FIG. **5**J illustrates a collection of vertical flow channels **520** that are rectangular with rounded ends. In FIG. **5**J, dimension X_1 could be 0.275 inches and dimensions X_2 and X_3 could each be 0.050 inches. Also, dimension Y_1 could be 0.386 inches, dimension Y_2 could be 0.350 inches, and dimension Y_3 could be 0.036 inches.

Although FIGS. **5**A through **5**J illustrate examples of flow channels inside ribs that separate electronic components within an electronics enclosure, various changes may be made to FIGS. **5**A through **5**J. For example, the cross-sections and dimensions described above are for illustration only. A flow channel or a collection of flow channels through a rib in an electronics enclosure could have any suitable cross-section, and the flow channel(s) could have any suitable dimensions. Also, the electronics enclosures described above could use any other suitable flow channels and are not limited to those shown here. For instance, the selection of the flow channels could be based on the thermal and flow properties needed for a specific application. Further, note that a combination of flow channels could be used.

FIGS. **6**A and **6**B illustrate example channels inside walls of an electronics enclosure in accordance with this disclosure. In the electronics enclosures described above, the flow channels in the fluid transport structures are within the ribs of the electronics enclosures. As a result, cooling fluid physically flows through those ribs during operation. In FIGS. **6**A and **6**B, however, multiple channels allow cooling fluid to flow through the walls of an electronics enclosure without actually flowing through the ribs. In FIG. **6**A, for example, a portion **600** of an electronics enclosure includes a wall **602** and multiple ribs **604**. The wall **602** includes multiple channels **606** (in this case five channels). The channels **606** represent passages lined with at least one material resistant to corrosion from the cooling fluid (such as nickel). The remainder of the wall **602** could be formed from at least one other material such as aluminum (although as noted above a plating or coating could be placed on the wall). In FIG. **6**A, the channels **606** have a generally circular cross-section. FIG. **6**B shows channels **608** having a cross-sectional shape similar to that shown in FIG. **5**B. In particular embodiments, the channels can run substantially perpendicular to the ribs **604** of the enclosure.

In one aspect of operation, cooling fluid can be pumped, injected, or otherwise provided into one or more of the channels **606-608**. For example, cooling fluid could be provided to all channels **606-608** at a first end of the wall **602** and recovered from the channels **606-608** at a second end of the wall **602**. As another example, cooling fluid could be provided to some channels **606-608** at a first end of the wall **602** and recovered from other channels **606-608** at the first end of the wall **602**, such as when two channel **606-608** are linked at the second end of the wall **602**. A channel **606-608** could reside along a single wall or wrap around multiple walls of the enclosure (such as when a U-shaped channel is used to cool ribs on opposite sides of the enclosure).

Note that this approach might provide less thermal performance than the enclosures of FIGS. **1** through **4**C since the cooling fluid removes heat from the walls of an enclosure rather than from the ribs of the enclosure. Still, adequate thermal performance could be obtained for various applications. Note that a process similar to that shown in FIGS. **2**A through **2**H could be used to fabricate an electronics enclosure having channels in its walls. For instance, a fluid transport structure of nickel or other corrosion-resistant material(s) could be fabricated over a form, and the form could be removed. The fluid transport structure could then be encased in an aluminum or other casting, where the fluid transport structure forms channels in the walls of the casting. The casting can then be processed to finalize the construction of an electronics enclosure.

Although FIGS. **6**A and **6**B illustrate examples of channels inside walls of an electronics enclosure, various changes may be made to FIGS. **6**A and **6**B. For example, any other suitable cross-sectional shape could be used for channels within walls of an electronics enclosure, including any of the cross-sections shown in FIGS. **5**A through **5**J.

In particular embodiments, any of the electronics enclosures described above could satisfy the following functional specifications. The electronics enclosures can be used with electronics consuming at least about 130 W of power per slot and in systems with electronics consuming at least about 1,500 W of power per cubic foot. The electronics enclosures could have the capacity to cool up to sixteen circuit boards each. Heat transfer efficiency of at least about 4.4 W/° C. per gallon of fluid (such as about 8 W/° C. or more) can be obtained between the cooling fluid and the mounting interface where the circuit boards or other electronics are mounted to the electronics enclosure. The electronics enclosures could have a minimum operational lifespan of at least seven years with less than an about 10% reduction in thermal performance during that time. The maximum flow rate of cooling fluid through an enclosure could be about one to about three gallons per minute (GPM), and the maximum pressure drop of cooling fluid through an enclosure could be about 4 PSI/GPM. In addition, the electronics enclosures described above could achieve significant weight reduction (such as about 25% or more) and could have similar fabrication costs (such as about 1.4 times or less) compared to conventional liquid-cooled enclosures.

Additional features could also be incorporated into any of the electronics enclosures described above. For example, the electronics enclosures could include protective coatings to handle relative humidity, salt fog, or cooling fluid exposure on the outer surfaces of the electronics enclosures. Also, various gaskets could be used to provide atmospheric pressure protection, submergence protection, and EMI shielding compliance. In addition, note that any feature in one or more of the electronics enclosures described above could be used in any other electronics enclosure described above. That is, the use of a feature is not limited to the specific drawing(s) in which that feature is shown, and any combination of features described above could be used.

The electronics enclosures described above could find use in a wide variety of systems and devices where cooling of electronic components is desired or required. For example, these electronics enclosures could be used in any device or system using high-power and densely-packaged electronics. FIGS. **7**A and **7**B illustrate an example system **700** using electronics enclosures with high thermal performance in accordance with this disclosure. In this particular example, the system **700** represents a missile defense system for naval vessels, ground troops, and other military forces. The system **700** generally operates to destroy incoming missiles, rockets, artillery shells, or other ordnance. This particular system **700** represents a PHALANX close-in weapon system (CIWS), although other types of weapon systems could be used.

As shown in FIG. **7**A, the system **700** includes a Gatling gun **702**, such as a 20 mm gun, which is used to fire rounds at incoming ordnance. A radar system **704** is used to track the incoming ordnance so that the gun **702** can be aimed properly. The gun **702** is mounted on a swivel base **706**, which can move to position the gun **702**. The system **700** also includes a microwave cabinet **708**, which contains various components used in conjunction with the radar system **704**.

The system **700** further includes a large electronics enclosure (ELX) **710**, which includes a number of drawers **712** that house various electronic components supporting operation of the system **700**. FIG. **7**B illustrates the ELX **710** in greater detail. As shown in FIG. **7**B, the ELX **710** includes the drawers **712**, which could slide into and out of the ELX **710**. The ELX **710** also includes left and right panel assemblies **714-716**, an electro-mechanical power supply **718**, an electronics power supply **720**, a step-down transformer **722**, an inverter-relay assembly **724**, a voltage and phase sensor **726**, and a radio frequency interference (RFI) filter **728**. Additional details regarding the PHALANX system are known to those skilled in the art and are not provided here.

Conventional PHALANX systems use a large blower to force air through a liquid-to-air heat exchanger into the ELX **710** and through the drawers **712**. In accordance with this disclosure, however, the drawers **712** can be implemented using any of the liquid-cooled electronics enclosures described above in FIGS. **1** through **6**B. The PHALANX system uses a de-ionized ethylene glycol water mixture that is highly corrosive to bare aluminum parts, so conventional liquid-based cooling systems that use aluminum could not be used. Moreover, conventional liquid-based cooling systems that use stainless steel cannot provide the necessary thermal performance. In contrast, the electronics enclosures described above can be used with a de-ionized ethylene glycol water mixture as the cooling fluid and can provide the necessary thermal performance.

Although FIGS. **7**A and **7**B illustrate one example of a system **700** using electronics enclosures with high thermal performance, various changes may be made to FIGS. **7**A and **7**B. For example, the electronics enclosures described above could be used in any other suitable device or system.

FIG. **8** illustrates an example method **800** for forming an electronics enclosure with high thermal performance in accordance with this disclosure. As shown in FIG. **8**, one or more fluid transport structures are formed around one or more forms at step **802**. This could include, for example, electroforming or otherwise depositing pure or substantially pure nickel around an aluminum, plastic, or other form structure. The one or more forms are then removed at step **804**. This could include, for example, etching, drilling, burning, or otherwise removing the aluminum, plastic, or other form structure from within the fluid transport structure(s).

The one or more fluid transport structures are encased within a casting at step **806**. This could include, for example, casting aluminum or other material(s) around the fluid transport structure(s) using the fluid transport structure(s) as a mold core. Note that the term "casting" (when referring to a structure) encompasses any structure encasing one or more fluid transport structures. The casting is then processed to create a finished enclosure structure at step **808**. This could include, for example, machining the aluminum casting using conventional or other aluminum machining techniques.

At this point, the finished enclosure structure can be used in any suitable manner. For instance, electronic components can be inserted into the enclosure structure at step **810**, and cooling fluid can be provided to the fluid transport structure(s) at step **812**. This could include, for example, providing a corrosive de-ionized ethylene glycol water mixture to the fluid transport structure(s) in order to pull heat away from the electronic components.

Although FIG. **8** illustrates one example of a method **800** for forming an electronics enclosure with high thermal performance, various changes may be made to FIG. **8**. For example, any suitable operations could be performed during each step of FIG. **8**.

It may be advantageous to set forth definitions of certain words and phrases used throughout this patent document. The terms "include" and "comprise," as well as derivatives thereof, mean inclusion without limitation. The term "or" is inclusive, meaning and/or. The phrase "associated with," as well as derivatives thereof, may mean to include, be included within, interconnect with, contain, be contained within, connect to or with, couple to or with, be communicable with, cooperate with, interleave, juxtapose, be proximate to, be bound to or with, have, have a property of, have a relationship to or with, or the like.

While this disclosure has described certain embodiments and generally associated methods, alterations and permutations of these embodiments and methods will be apparent to those skilled in the art. Accordingly, the above description of example embodiments does not define or constrain this disclosure. Other changes, substitutions, and alterations are also possible without departing from the spirit and scope of this disclosure, as defined by the following claims.

What is claimed is:

1. An apparatus comprising:

an electronics enclosure having multiple ribs configured to separate electronic components, each rib having a length from a first end to a second end; and

at least one fluid transport structure encased within the electronics enclosure, each fluid transport structure including multiple pipes and multiple flow channels;

wherein each flow channel is located substantially within a corresponding one of the ribs of the electronics enclosure such that the flow channel extends substantially along the length of that rib from the first end to the second end, and the pipes are configured to transport cooling fluid to and from the flow channels; and

wherein the at least one fluid transport structure is resistant to corrosion caused by the cooling fluid and the electronics enclosure is susceptible to corrosion caused by the cooling fluid.

2. The apparatus of claim **1**, wherein the at least one fluid transport structure consists essentially of a single layer of a corrosion resistant material.

3. The apparatus of claim **2**, wherein:

the single layer of the at least one fluid transport structure consists essentially of nickel; and

the electronics enclosure consists essentially of aluminum.

4. The apparatus of claim **1**, wherein:

the apparatus comprises multiple fluid transport structures;

the multiple fluid transport structures are encased on opposite sides of the electronics enclosure;

one pipe in each fluid transport structure is configured to provide the cooling fluid to the flow channels located along one side of the electronics enclosure; and

another pipe in each fluid transport structure is configured to receive the cooling fluid from the flow channels located along one side of the electronics enclosure.

5. The apparatus of claim **1**, wherein:

the apparatus comprises a single fluid transport structure;

one pipe in the fluid transport structure is configured to provide the cooling fluid to the flow channels located along two sides of the electronics enclosure; and

another pipe in the fluid transport structure is configured to receive the cooling fluid from the flow channels located along two sides of the electronics enclosure.

6. The apparatus of claim **5**, wherein the single fluid transport structure comprises two U-shaped pipes fluidly coupled to different ends of the flow channels.

7. The apparatus of claim **1**, wherein each pipe is coupled to at least one port configured to receive or provide the cooling fluid.

8. The apparatus of claim **1**, wherein:

the at least one fluid transport structure is integrally formed of nickel using metal deposition; and

the electronics enclosure is formed of aluminum cast around the at least one fluid transport structure.

9. The apparatus of claim **1**, wherein at least one of the flow channels has a cross-sectional shape comprising one of:

a central area surrounded by a plurality of interconnected partial or near-complete circular areas; or

a plurality of near-complete circular areas arranged in a two-dimensional matrix and interconnected via thinner paths to a smaller central area.

10. An apparatus comprising:

an electronics enclosure surrounding an open space, wherein an inside surface of the electronics enclosure comprises multiple ribs configured to separate electronic components disposed within the open space, each rib having a length from a first end to a second end; and

at least one fluid transport structure encased within the electronics enclosure, each fluid transport structure including multiple pipes and multiple flow channels;

wherein each flow channel is located substantially within a corresponding one of the ribs of the electronics enclosure such that the flow channel extends substantially along the length of that rib from the first end to the second end, and the pipes are configured to transport cooling fluid to and from the flow channels; and

wherein the at least one fluid transport structure is resistant to corrosion caused by the cooling fluid and the electronics enclosure is susceptible to corrosion caused by the cooling fluid.

11. The apparatus of claim **10**, wherein the at least one fluid transport structure consists essentially of a single layer of a corrosion resistant material.

12. The apparatus of claim **11**, wherein:

the single layer of the at least one fluid transport structure consists essentially of nickel; and

the electronics enclosure consists essentially of aluminum.

13. The apparatus of claim **10**, wherein:

the apparatus comprises multiple fluid transport structures;

the multiple fluid transport structures are encased on opposite sides of the electronics enclosure;

one pipe in each fluid transport structure is configured to provide the cooling fluid to the flow channels located along one side of the electronics enclosure; and

another pipe in each fluid transport structure is configured to receive the cooling fluid from the flow channels located along one side of the electronics enclosure.

14. The apparatus of claim **10**, wherein:

the apparatus comprises a single fluid transport structure;

one pipe in the fluid transport structure is configured to provide the cooling fluid to the flow channels located along two sides of the electronics enclosure; and

another pipe in the fluid transport structure is configured to receive the cooling fluid from the flow channels located along two sides of the electronics enclosure.

15. The apparatus of claim **14**, wherein the single fluid transport structure comprises two U-shaped pipes fluidly coupled to different ends of the flow channels.

16. The apparatus of claim **10**, wherein each pipe is coupled to at least one port configured to receive or provide the cooling fluid.

17. A system comprising:

an artillery device; and

a cabinet comprising:

an electronics enclosure having multiple ribs configured to separate electronic components associated with the artillery device, each rib having a length from a first end to a second end; and

at least one fluid transport structure encased within the electronics enclosure, each fluid transport structure including multiple pipes and multiple flow channels;

wherein each flow channel is located substantially within a corresponding one of the ribs of the electronics enclosure such that the flow channel extends substantially along the length of that rib from the first end to the second end, and the pipes are configured to transport cooling fluid to and from the flow channels; and

wherein the at least one fluid transport structure is resistant to corrosion caused by the cooling fluid and the electronics enclosure is susceptible to corrosion caused by the cooling fluid.

18. The system of claim **17**, wherein the at least one fluid transport structure consists essentially of a single layer of a corrosion resistant material.

19. The system of claim **18**, wherein:

the single layer of the at least one fluid transport structure consists essentially of nickel; and

the electronics enclosure consists essentially of aluminum.

20. The system of claim **17**, wherein:

the apparatus comprises multiple fluid transport structures;

the multiple fluid transport structures are encased on opposite sides of the electronics enclosure;

one pipe in each fluid transport structure is configured to provide the cooling fluid to the flow channels located along one side of the electronics enclosure; and

another pipe in each fluid transport structure is configured to receive the cooling fluid from the flow channels located along one side of the electronics enclosure.

21. The system of claim **17**, wherein:

the apparatus comprises a single fluid transport structure;

one pipe in the fluid transport structure is configured to provide the cooling fluid to the flow channels located along two sides of the electronics enclosure; and

another pipe in the fluid transport structure is configured to receive the cooling fluid from the flow channels located along two sides of the electronics enclosure.

22. The system of claim **21**, wherein the single fluid transport structure comprises two U-shaped pipes fluidly coupled to different ends of the flow channels.

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